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I, KAY WARD, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PP 7826 for a patent by THE UNIVERSITY OF WESTERN AUSTRALIA filed on 21 December 1998.

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PRIORITY DOCUMENT**



WITNESS my hand this  
Eighteenth day of February 2000

A handwritten signature in cursive script that appears to read "K. Ward".

KAY WARD  
TEAM LEADER EXAMINATION  
SUPPORT AND SALES

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ORIGINAL

AUSTRALIA

*Patents Act 1990*

**PROVISIONAL SPECIFICATION**

Invention Title: "Noise Reduction Apparatus"

The invention is described in the following statement:

TITLE

"Noise Reduction Apparatus"

FIELD OF THE INVENTION

This invention relates to a noise reduction apparatus. The invention has  
5 particular, although not exclusive, utility in relation to use in cabins of heavy  
vehicles, such as mining vehicles, where low frequency noise can present an  
occupational hazard.

BACKGROUND ART

Most prior noise reduction systems for cabins have employed a feed-forward  
10 control system using a filtered-x least mean square (LMS) algorithm. One such  
system is disclosed in US patent specification 5,245,664. Whilst providing an  
adaptive controller, the conventional filtered-x LMS controller is known to have a  
slow convergence rate. As a result, control systems making use of the filtered-x  
LMS algorithm can perform poorly when the noise changes abruptly, such as  
15 when the vehicle changes gear.

This problem has, to some extent, been addressed by using pre-compiled feed-  
forward control systems, such as those described in US patent specifications  
4,506,380, 5,692,052 and 5,758,311. Such control systems do not suffer from  
slow convergence, however the pre-compiled nature of the controller limits the  
20 adaptability of the controller.

Accordingly, there exists a need for an adaptive controller having a reasonable  
convergence rate.

In addition, field trials of noise cancellation systems have shown that operators  
of heavy mining equipment have individual preferences regarding the level of

noise attenuation at certain frequencies. Some drivers use the sound of the engine as part of their sensory input in controlling the vehicle. Accordingly, it would be desirable to provide a noise reduction system in which the level of attenuation can be adjusted or at least selected from a plurality of predefined.

5 configurations:

DISCLOSURE OF THE INVENTION

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the  
10 exclusion of any other integer or group of integers.

In accordance with one aspect of this invention, there is provided a noise reduction apparatus for an enclosure in a vehicle comprising:

first sensor means to generate a reference signal;

second sensor means to generate an error signal;

15 control means responsive to the reference signal to produce a control signal;

a transducer responsive to the control signal;

said control means comprises user preference means arranged to process the error signal, and adaptive means responsive to the processed  
20 error signal to define parameters of the control means.

Preferably, the first sensor means comprises a plurality of first sensors, each associated with a source of noise.

Preferably, the reference signal is formed from the outputs of the first sensors.

Preferably, the second sensor means is provided adjacent to the operator's head.

Preferably, the second sensor means comprises two microphones, one provided adjacent each ear of the operator.

- 5 Preferably, the apparatus comprises a plurality of transducers.

Preferably, the transducers are audio transducers and/or vibration transducers.

Preferably, at least one transducer has a first sensor provided therewith.

- Preferably, the control means further comprises a first controller responsive to the reference signal to produce the control signal for the transducer, a plant model responsive to the reference signal to produce a signal input to a second controller, signal generation means for producing a further error signal from the output of the second controller, the output of the first controller and the error signal from the second sensor means, the further error signal forming the input to the user preference means, the adaptive means being arranged to adjust the parameters of the first and second controllers simultaneously.
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In one arrangement, the controller is a feed-forward controller.

In an alternative arrangement, the controller is a feedback controller.

In a still further arrangement, the controller comprises a feed-forward and a feedback controller.

- 20 Preferably, in one arrangement, the reference signal is replaced by a further signal produced by the signal generation means.

Preferably, the vibration transducers are provided at a node or antinode of a surface of the enclosure.

Preferably, the apparatus further comprises monitoring means arranged to monitor the noise level in the enclosure and disable the control means if the noise exceeds a predetermined threshold.

Preferably, said monitoring means resets the parameters of the first and second controller prior to enabling the control means.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1a and 1b are side and front views, respectively, of a vehicle cabin incorporating the noise reduction apparatus according to the preferred embodiment of the invention;

10 Figure 2 is a block diagram of a feed-forward control circuit of the embodiment; and

Figure 3 is a block diagram of a feedback control circuit of the embodiment.

#### BEST MODE(S) FOR CARRYING OUT THE INVENTION

The embodiment relates to a noise reduction apparatus denoted generally at 10 provided in a cabin 12 of a heavy mining vehicle. The noise in the cabin 12 of such a vehicle is often the product of several noise sources, such as the engine, the exhaust/muffler system and auxiliary equipment such as hydraulics, compressors, air conditioning units and fans, as well as noise sources external to the vehicle. Each of these noise sources can produce noise in the cabin 12 either by transmission of sound into the cabin 12, or by causing vibrations in the structure of the cabin 12, which in turn creates noise within the cabin 12. The embodiment uses a controller having a two channel feedforward circuit and a single channel feedback circuit.

In the embodiment, the cabin 12 includes a floor panel 14, a seat 16 attached to the floor 14 and a ceiling panel 18.

The noise reduction apparatus 10 of the embodiment comprises two first sensors 20a and 20b, three second sensors 22a, 22b and 22c, a controller 24 and three transducers 26a, 26b and 26c.

The first sensors 20a comprises a vibration sensor and is provided adjacent the  
5 vehicle's engine 28. The first sensor 20b comprises a microphone provided near  
the vehicle's muffler 30. Each of the first sensors 20a and 20b is connected to  
the controller 24. The controller 24 forms a reference signal from information  
received from the first sensors 20a and 20b.

The second sensors 22a and 22b each comprise a microphone provided above  
10 the seat 16. The second sensors 22a and 22b are provided spaced apart at  
opposite sides of the seat 16 such that in use, the operator's head would be  
received between the second sensors 22a and 22b. The second sensors 22a  
and 22b are connected to the controller 24.

The second sensor 22c comprises a vibration sensor that is provided on the floor  
15 panel 14 of the cabin 12. The second sensor 22c is connected to the controller  
24.

In the embodiment, the controller 24 comprises a 2 channel feedforward circuit  
24a and a single channel feedback circuit 24b. The second sensors 22a and  
22b each provide an error signal to one channel of the feedforward circuit 24a of  
20 the controller 24. The second sensor 22c provides an error signal to the  
feedback control circuit 24b.

The transducers 26a and 26b comprise audio transducers such as loud speaker  
drivers. The transducers 26a and 26b are attached to the ceiling panel 18 of the  
cabin 12 and are positioned generally above the corresponding second sensor  
25 22a and 22b, respectively. In other embodiments, the transducers may be  
provided at other locations, depending upon the installation requirements and  
the available space in the cabin.

The transducer 26c comprises a vibration transducer attached to the floor panel 14. The second sensor 22c and the transducer 26c are provided on opposite sides of the floor panel 14 so as to be co-located one above the other. The transducer 26c may be in the form of a piezoelectric transducer or a magnetostriuctive actuator. It is preferred that if used, the piezoelectric transducer is placed at a node of vibrations in the floor panel 14, whilst a magnetostriuctive actuator is provided at an antinode of vibrations in the floor panel 14. Transducers may be in other locations depending on installation requirements.

10 Each of the transducers 26a, 26b and 26c are connected to the controller 24 and receive control signals therefrom. The transducers 26a and 26b each receive a control signal from one channel of the feedforward control circuit 24a, and the transducer 26c receives a control signal from the feedback control circuit 24b.

Figure 2 shows a block diagram of the feedforward control circuit 24a. A reference signal 32 is formed from the signals received from the first sensors 20a and 20b. Although not shown in figure 2, the signals received from the first sensors 20a and 20b may be the subject of signal conditioning as part of the formation of the reference signal 32. Such signal conditioning may include attenuation, delay and/or filtering. The purpose of the signal conditioning is to increase the correlation between the reference signal 32 and the noise (shown in figure 3 at 34) in the cabin 12, improve the signal to noise ratio and adjust the relative balance between the signals received from the first sensors 20a and 20b.

A plant 36 is shown in figure 2, representing the electro-acoustic system corresponding to the transducers 26a and 26b and the acoustic path between said transducers and the region about the user's head, where noise reduction is desired.

The controller 24 includes a first control system 38, an adaptive LMS system 40 and a shaping filter 42.

The first control system 38 receives the reference signal 32 and, based on its current parameters, produces a control signal shown at 44. The control signal

5 44 is sent to the transducers which form part of the plant 36. The error signal, shown at 46, produced by the second sensors 22a and 22b is the sum of the noise 34 and the response of the plant 36 to the control signal 44.

Existing feed-forward controllers would pass the error signal 46 into an adaptive LMS system along with the reference signal 32 so that the adaptive LMS system

10 can update the parameters of the first control system 38. However, this would require the adaptive LMS system to be a filtered-x LMS system, which has a slow convergence.

To avoid this problem, the controller 24 includes a plant model 48, a second control system 50 and a signal generating means 52. The reference signal 32 is

15 input to the plant model 48, and the output of the plant model is input to the second control system 50 and the adaptive LMS system 40. The output of the second control system 50 is input to the signal generating means 52. The error signal 46 is also input to the signal generating means 52. The signal generating means 52 includes a further plant model 48 which takes as an input the control

20 signal 44. The output of the further plant model 48 is subtracted from the error signal 46 to arrive at a model of the noise 34 shown at 54. The model of the noise 54 is then combined with the output of the controller 50 to produce a second error signal at 56. Advantageously, the second error signal 56 allows the adaptive LMS system 40 to use traditional LMS convergence rates rather

25 than the slow filtered-x convergence rate.

The second error signal 56 is input to the shaping filter 42. The output of the shaping filter 42 is input to the adaptive LMS system 40. The adaptive LMS system 40 then makes adjustments to the operational parameters of the first and

second control systems 38 and 50 in order to minimise the filtered error signal input to the adaptive LMS system 40. The same changes are made to the parameters of both the control systems 38 and 50, such that the first and second controllers 38 and 50 have the same parameters.

- 5 The shaping filter 42 modifies the second error signal 56 prior to input to the adaptive LMS system 40. In this way, the user can customise the noise reduction achieved according to his or her preferences. Since the adaptive LMS system 40 attempts to minimise the signal appearing at its input from the output of the shaping filter 42, any portions of the second error signal 56 that are filtered or attenuated by the shaping filter 42 will not be attenuated to a significant degree by the controller 24. Depending upon the implementation adopted, the shaping filter 42 can offer customisable shaping or provide a plurality of predetermined shaping filters from which a user can select one.
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Figure 3 shows a block diagram of the feedback control circuit 24b. Like reference numerals are used in relation to figure 3 as were used in figure 2. The controller 24 shown in figure 3 differs from that shown in figure 2 in that a model noise signal 54 is used to replace the reference signal 32 by feeding the signal 54 back to the input of the first control system 38 and plant model 48. The feedforward control circuit 24b shown in figure 3 is used to control the transducer 26c.

Although not shown in the drawings, the noise reduction system 10 also includes a monitoring circuit that monitors the control signal 44. If the control signal 44 exceeds a predetermined threshold criteria, the controllers 50 and 38 are deactivated by the monitor circuit. This is to prevent noise within the cabin 12 reaching excessive levels if the controller 24 malfunctions and increases rather than decreases the noise within the cabin 12. The monitoring circuit also resets the parameters within the first and second controllers 38 and 50 back to an initial condition, following which the control systems 38 and 50 are enabled.

It should be appreciated that this invention is not limited to the particular embodiment described above.

For example, although the embodiment is described as having a two channel feed-forward control circuit and a single channel feedback control circuit, other 5 embodiments may use only one form of control circuit or may utilise any number of channels as needed.

It should be noted that the first sensors can take any appropriate form. In particular, in relation to the engine 28 it may be possible to utilise an indication of the speed of the engine from the tachometer or an audible signal derived from 10 the engine bay rather than a vibration signal.

Dated this TWENTY FIRST day of DECEMBER 1998.

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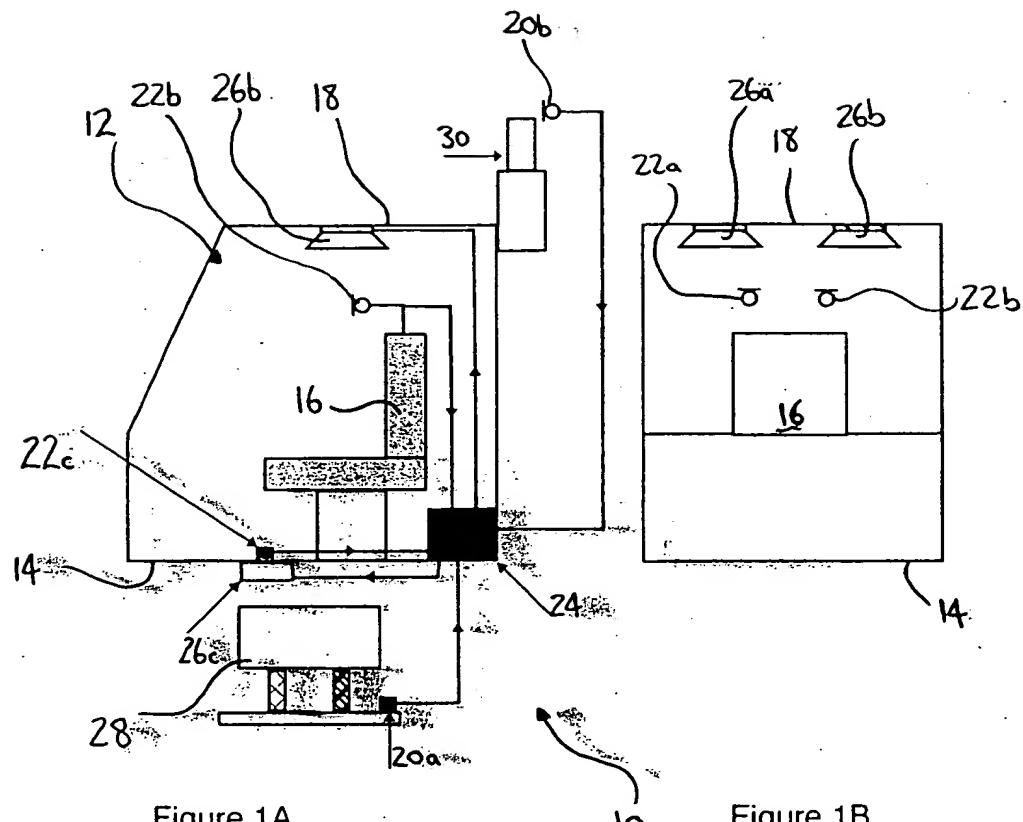


Figure 1A

Figure 1B

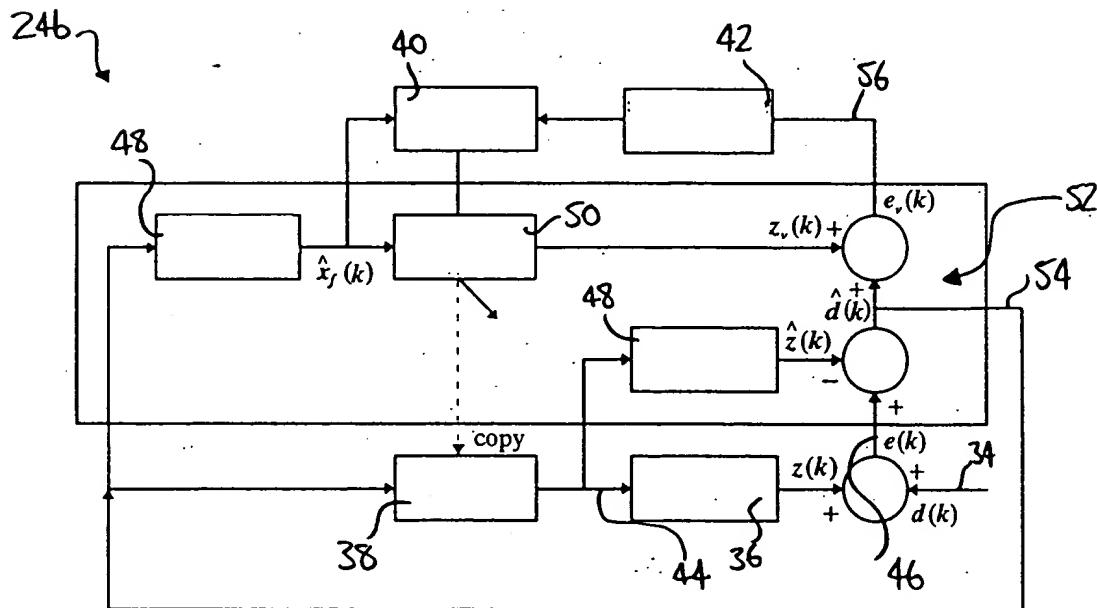
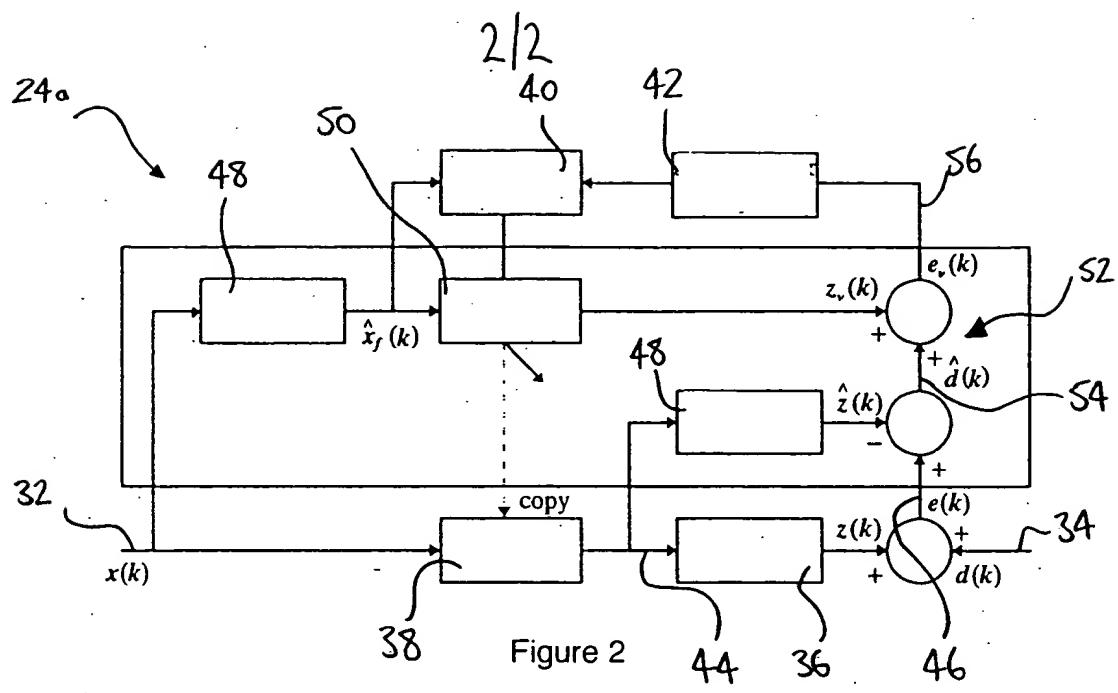


Figure 3